Evaluating the Potential of a Blocking Predictor in a Hybridized Dynamical-Statistical Model for Improved Week 3-4 Temperature and Precipitation Outlooks

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Innovim, LLC / NOAA / NWS / CPC

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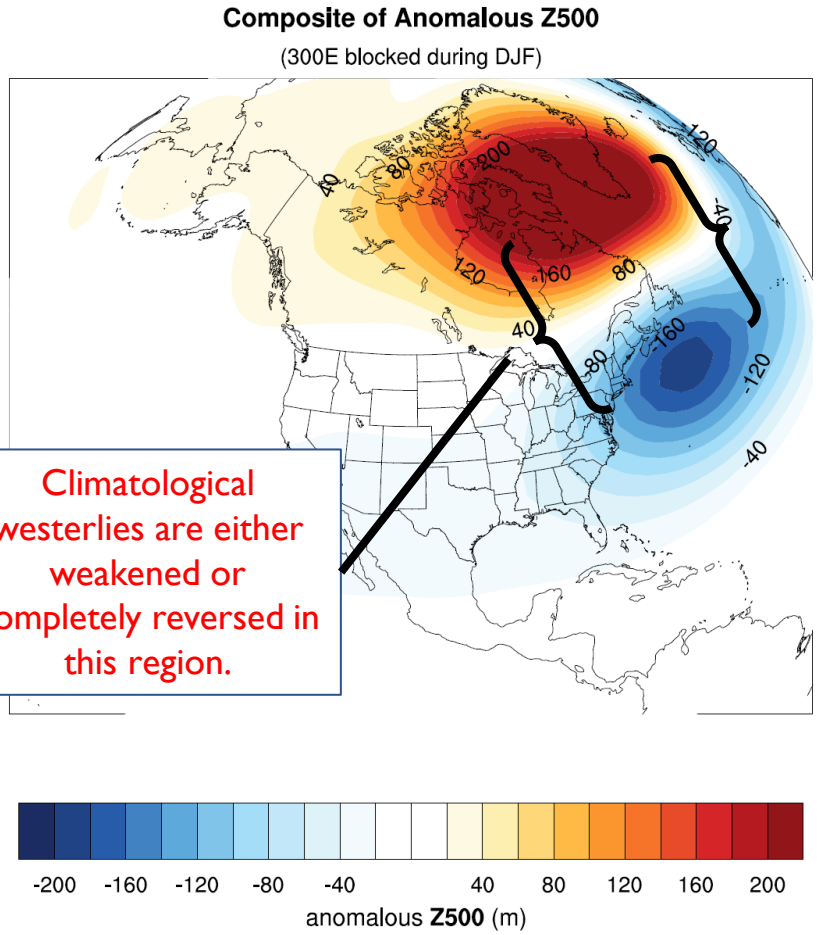
Why do we care about blocking?

Blocking



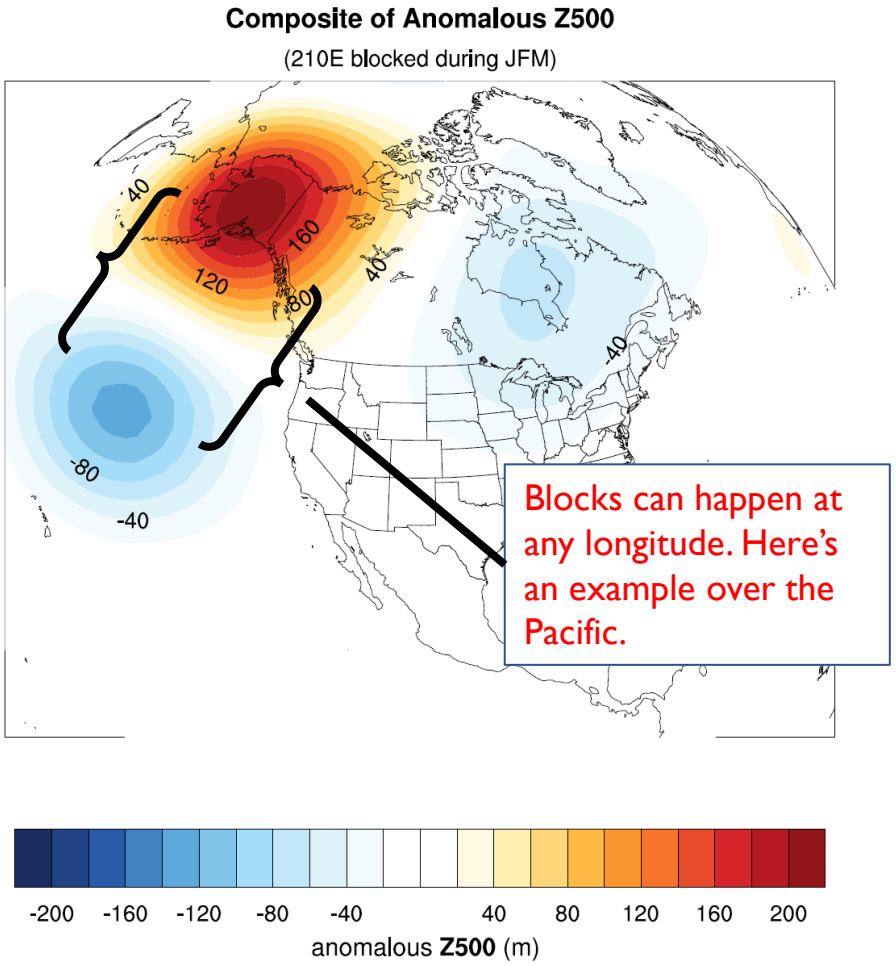
Climatological westerlies are either weakened or completely reversed in this region.

During blocking:

- An anomalous ridge exists to the north and an anomalous trough to its south.
- This results in a reversal of the climatological westerlies to easterlies.
- This reversal blocks the jet stream, forcing large-scale stationary waves and a diversion of the storm track.
- This pattern resembles the negative phase of the North Atlantic Oscillation (NAO).

The Tibaldi and Molteni (1990) index is one amongst many blocking indices (Barnes et al. 2012).

Blocking



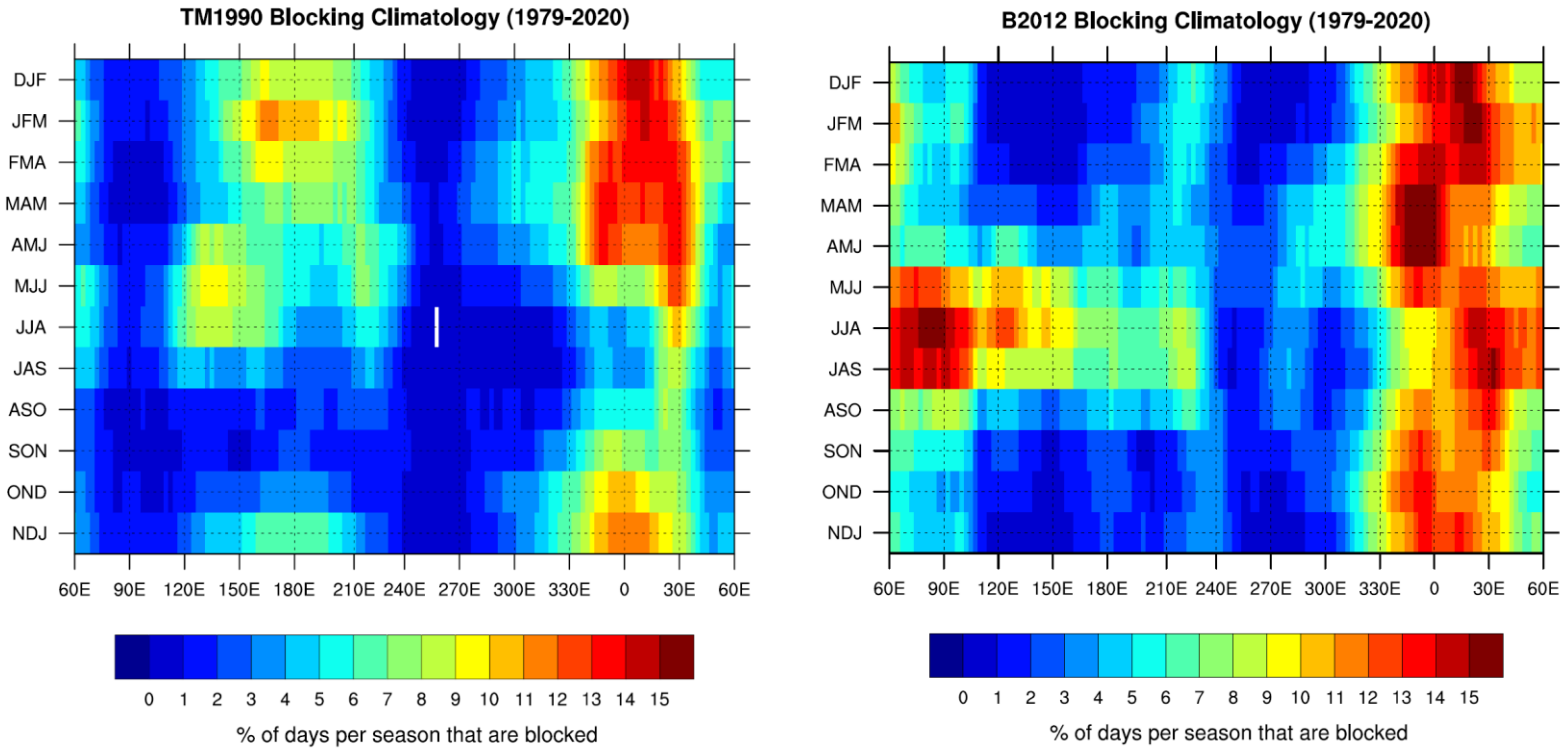
Examples of impacts:

- Extensive drought in the West (Wise 2016)
- Divert atmospheric rivers into Alaska (Baggett et al. 2015)
- **Extreme cold conditions** (Wang et al. 2010; Marinaro et al. 2015)
- Sudden stratospheric warmings (Martius et al. 2009; Butler et al. 2017)

Because blocks can persist for weeks, knowledge of blocking episodes and their surface impacts can perhaps lead to enhanced predictive skill of Week 3-4 temperature and precipitation across the United States.

Blocking

Climatological Blocking Frequency



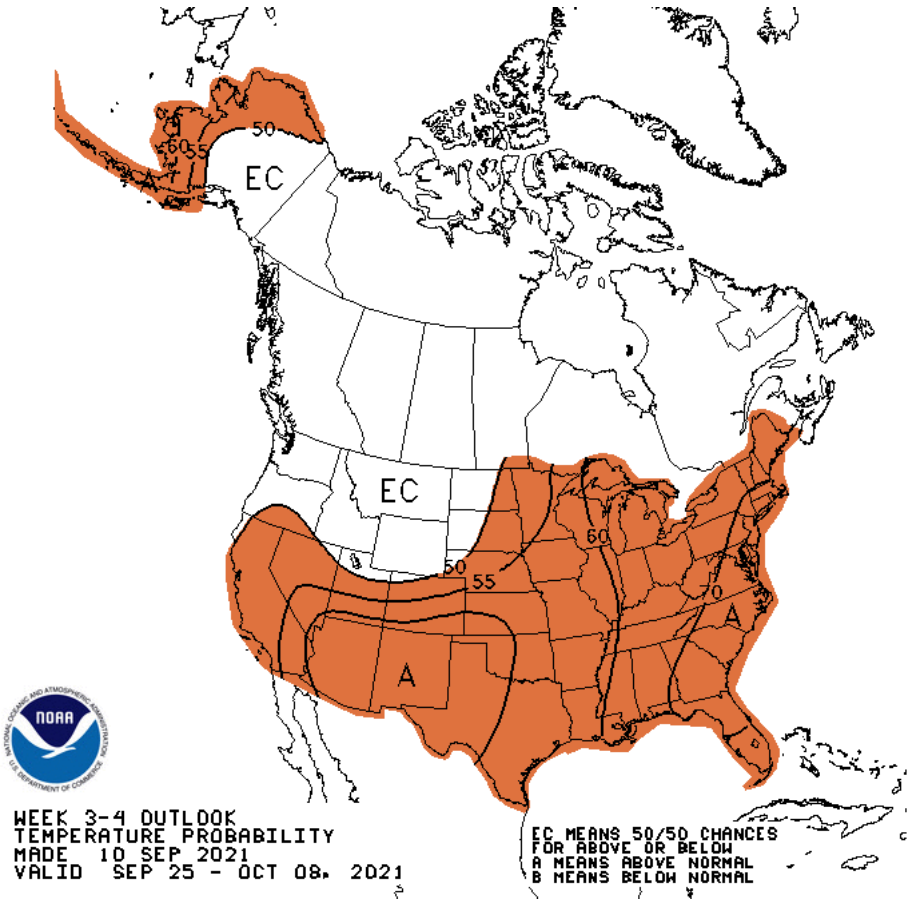
- Blocking occurs most frequently over the Atlantic sector.
- Which index should we use? Which blocking longitude?
- We tried many blocking-related indices, but we have found using the North Atlantic Oscillation (NAO) for the Atlantic and the Pacific-North American pattern (PNA) for the Pacific as "blocking" indices work well (Croci-Maspoli et al. 2007).
- Forthcoming results shown in this presentation use the NAO and PNA.

CPC Forecast Tools for Week 3-4

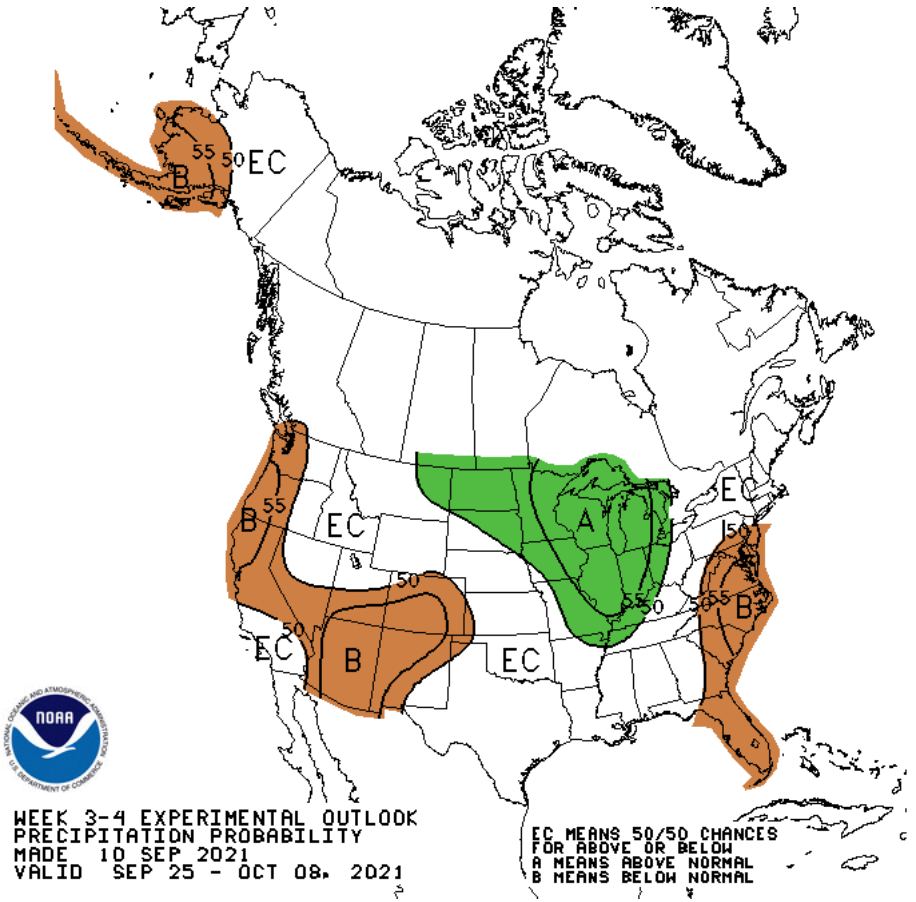
A brief overview of CPC's forecasting process…

CPC Forecast Tools for Week 3-4

Temperature



Precipitation



CPC Forecast Tools for Week 3-4

- Week 3-4 outlooks are issued once per week on Friday.
- A single forecaster (rotated weekly) is assigned to make the official outlook.
- The forecaster receives input from several tools:

1. Dynamical Models → GEFSv12, ECMWF, CFSv2, GEMv3, JMA, and models participating in SubX
2. Statistical Models
3. Model Blends
4. Intuition and Consistency

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2. Statistical Models
3. Model Blends
4. Intuition and Consistency

→ Multiple Linear Regression (MLR)*, Phase Model, Constructed Analog, Linear Inverse Model

*Because the dynamical models are typically deficient at simulating blocking, along with stratosphere-troposphere interactions at extended leads (Domeisen et al. 2020a,b; Quinting and Vitart 2019), we focus on improving CPC's MLR statistical model via a hybridization approach with blocking-related indices as forecasted by the dynamical models (e.g., Kim et al. 2021)

CPC Forecast Tools for Week 3-4

- Week 3-4 outlooks are issued once per week on Friday.
- A single forecaster (rotated weekly) is assigned to make the official outlook.
- The forecaster receives input from several tools:

1. Dynamical Models
2. Statistical Models
3. Model Blends → Equal-Weighted, Manual Blend, Autoblend
4. Intuition and Consistency

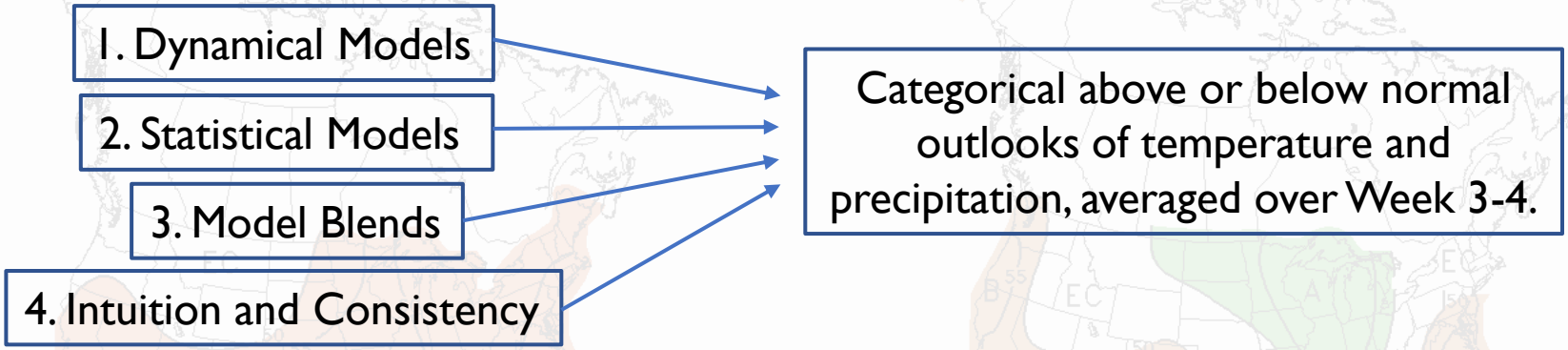
CPC Forecast Tools for Week 3-4

- Week 3-4 outlooks are issued once per week on Friday.
- A single forecaster (rotated weekly) is assigned to make the official outlook.
- The forecaster receives input from several tools:

1. Dynamical Models
2. Statistical Models
3. Model Blends
4. Intuition and Consistency → Peer input, recent model errors, persistence, soil moisture, coherent MJO

CPC Forecast Tools for Week 3-4

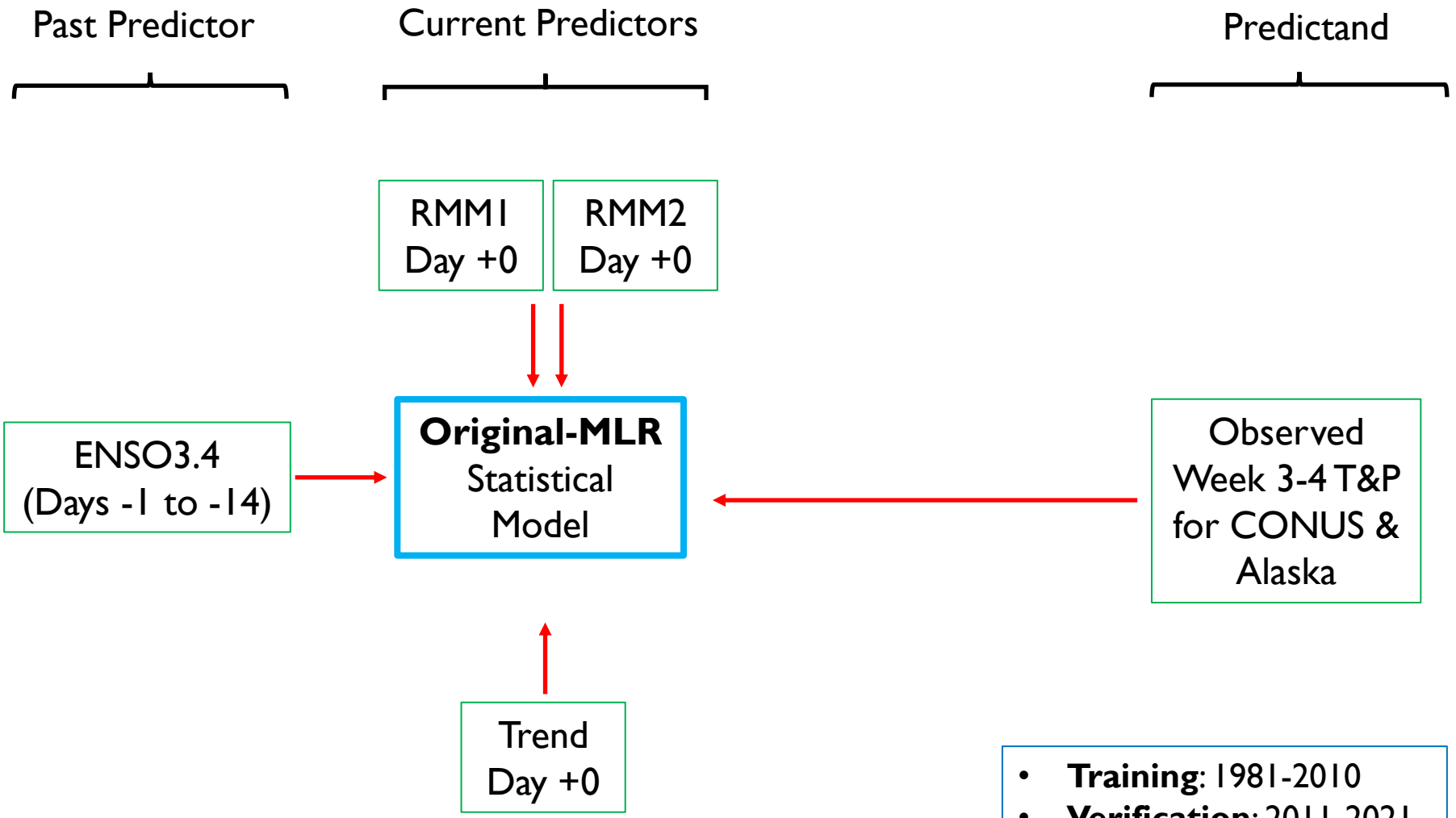
- Week 3-4 outlooks are issued once per week on Friday.
- A single forecaster (rotated weekly) is assigned to make the official outlook.
- The forecaster receives input from several tools:



- The forecaster presents a preliminary outlook at a weekly forecast discussion. Input is received, adjustments are made, and the outlook is made.
- Temperature outlooks are operational while precipitation outlooks are still experimental due to lack of skill.

What is CPC's Multiple Linear Regression Model (original-MLR)?

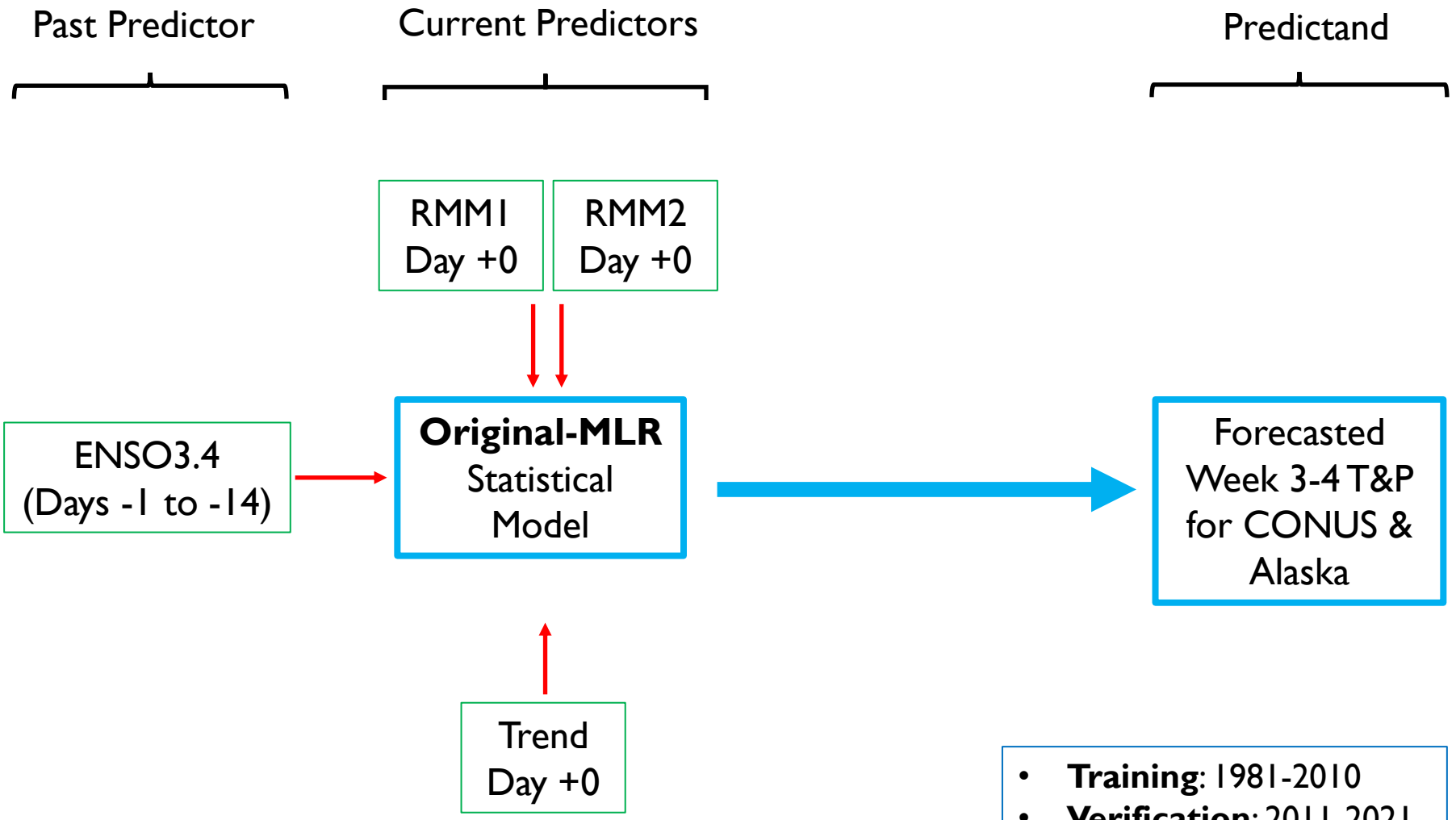
Original-MLR Schematic (Training)



- **Training**: 1981-2010
- **Verification**: 2011-2021

Harnos et al., in prep.

Original-MLR Schematic (Verification)



- **Training**: 1981-2010
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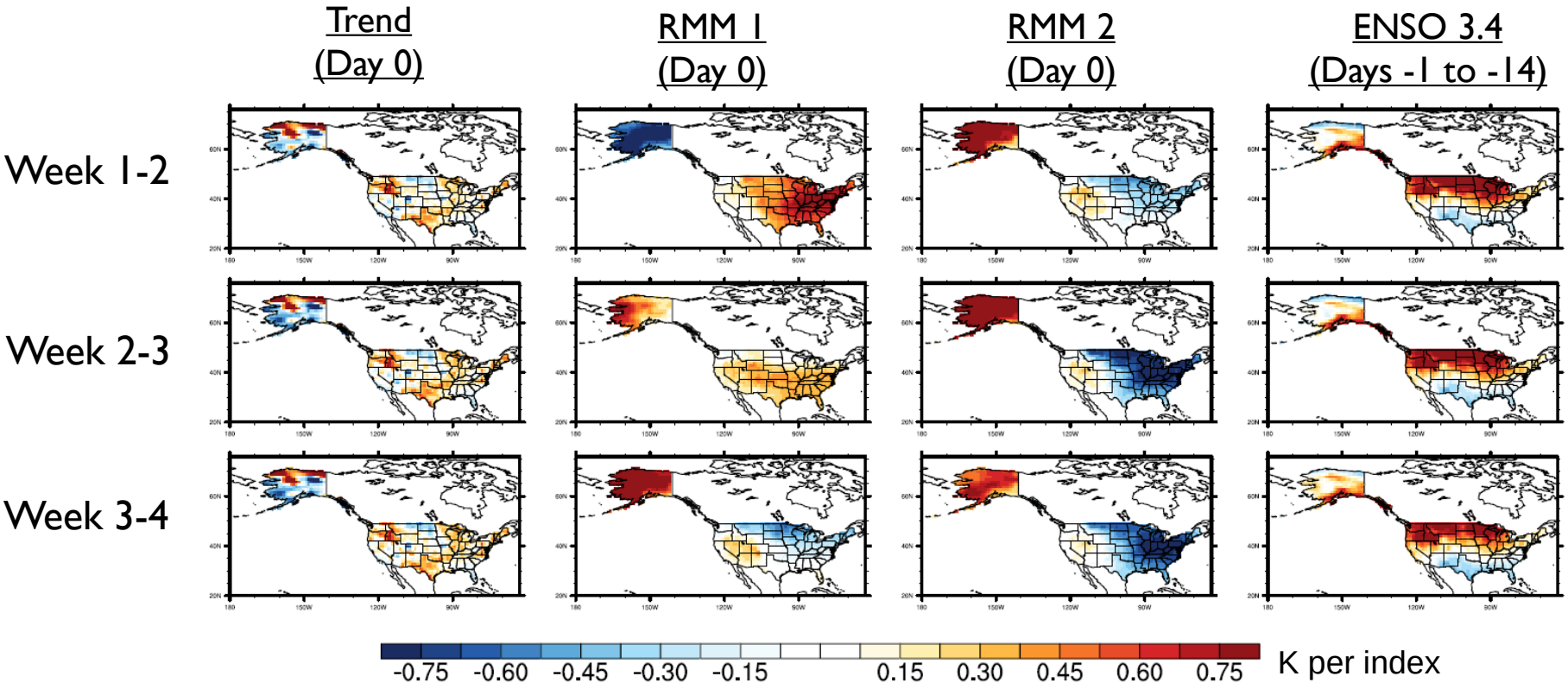
Harnos et al., in prep.

Original-MLR Regression Coefficients

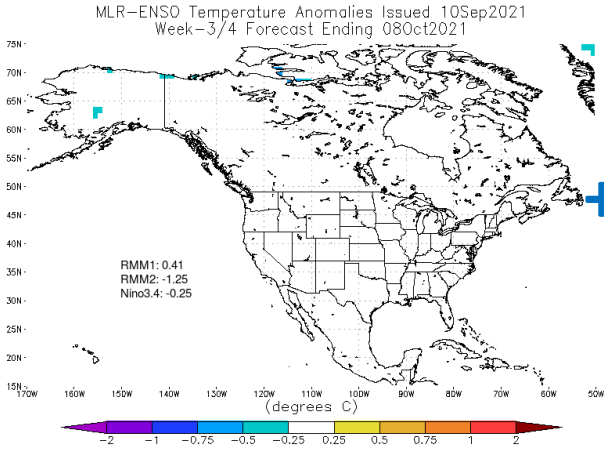
Temperature



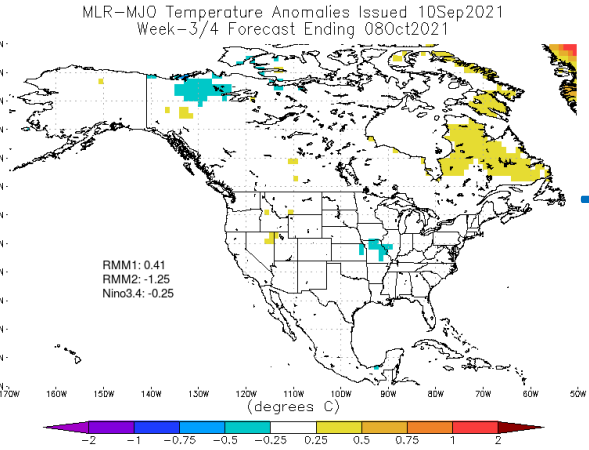
- Trend remains constant with lead-time
- MJO and ENSO signals persist out to Week 3-4

Original Multiple-Linear Regression Forecast

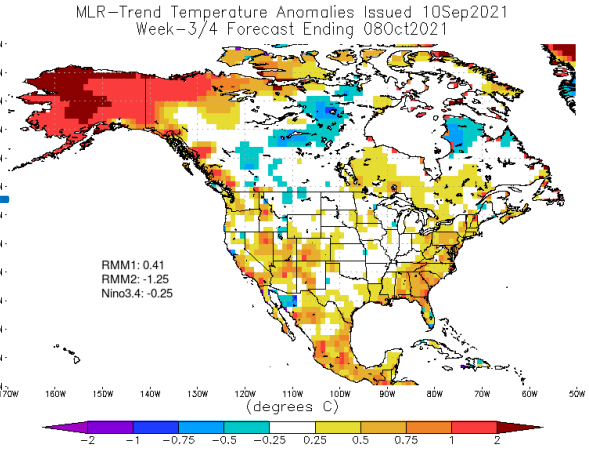
ENSO 3.4 (Days -1 to -14)

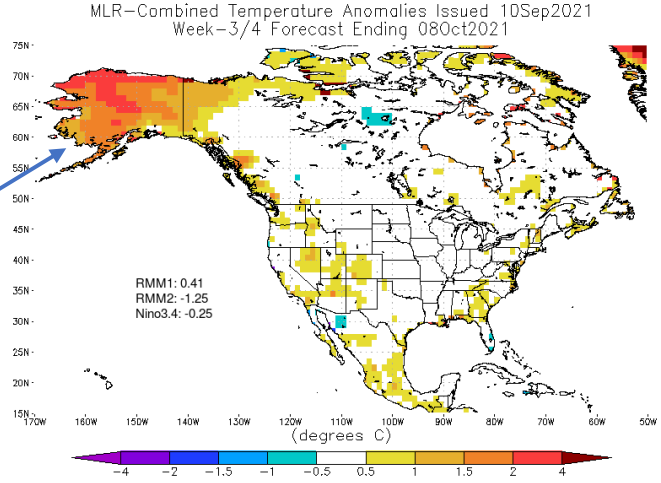


RMMs 1 & 2 (Day 0)



Trend (Day 0)





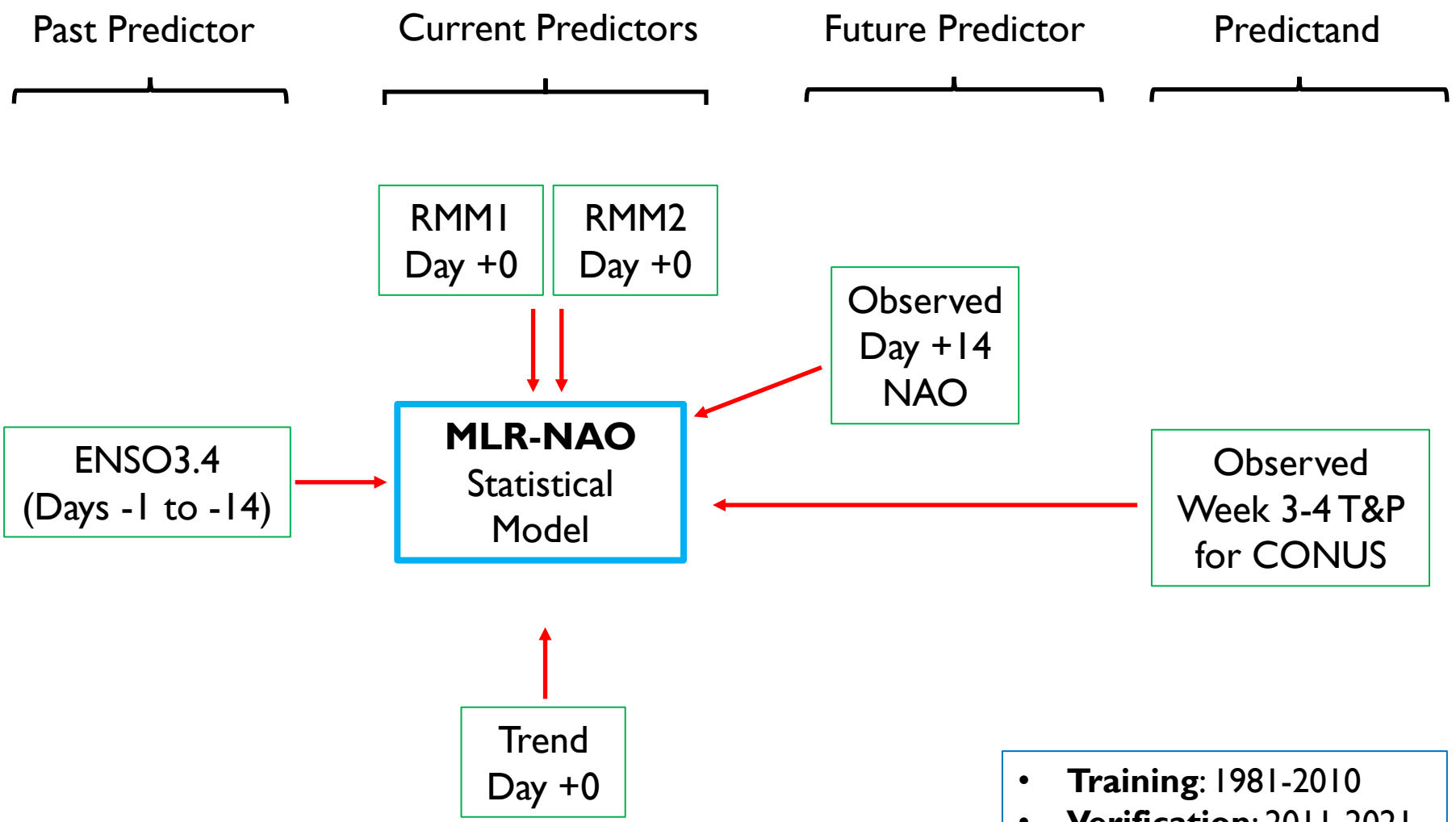
Significant warm signal in Alaska from the trend, which conflicted with some dynamical model guidance.

Week ENSO and MJO contributions, led to the trend dominating the original-MLR forecast.

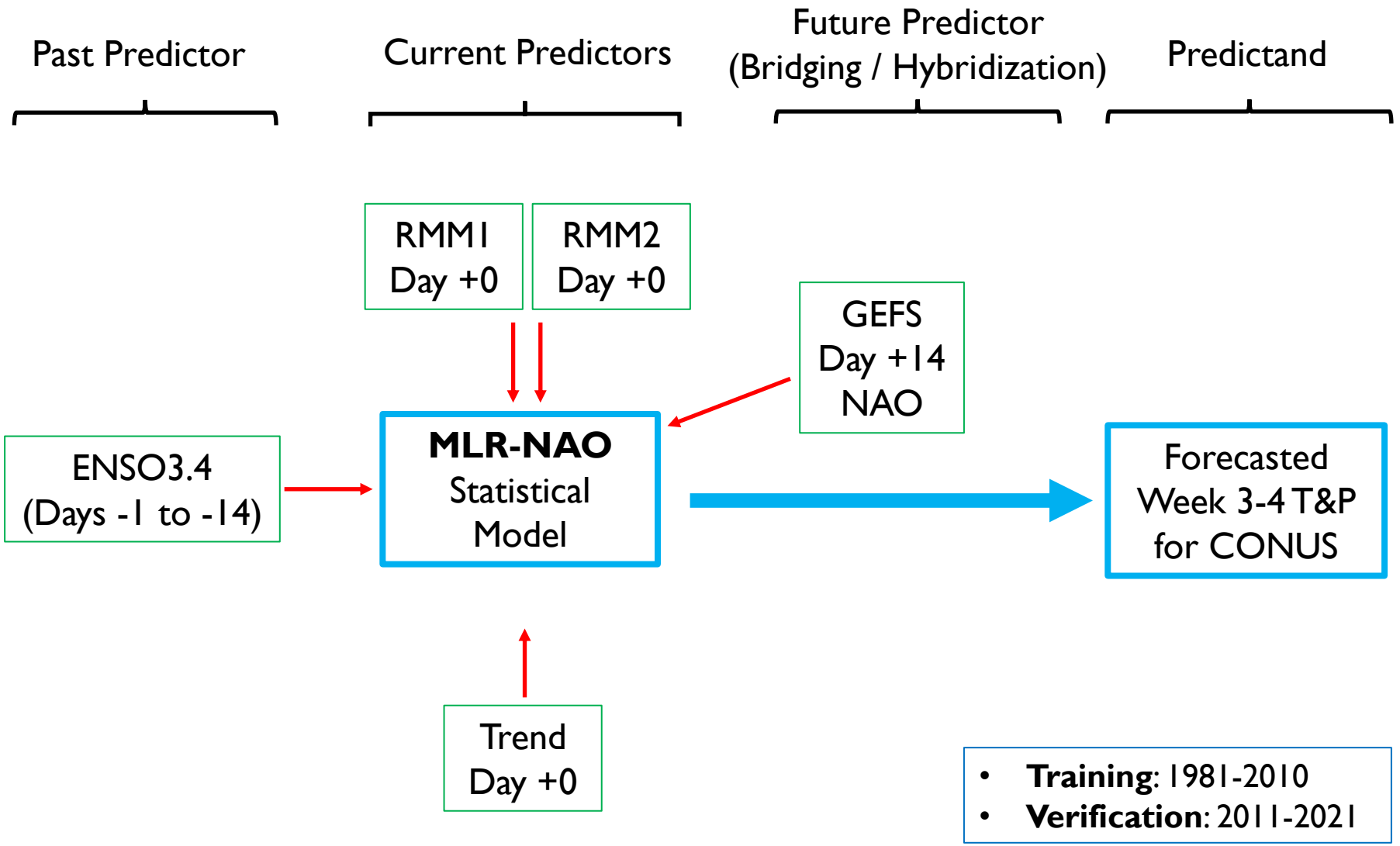
Harnos et al., in prep.

How does an MLR-NAO perform compared to the original-MLR?

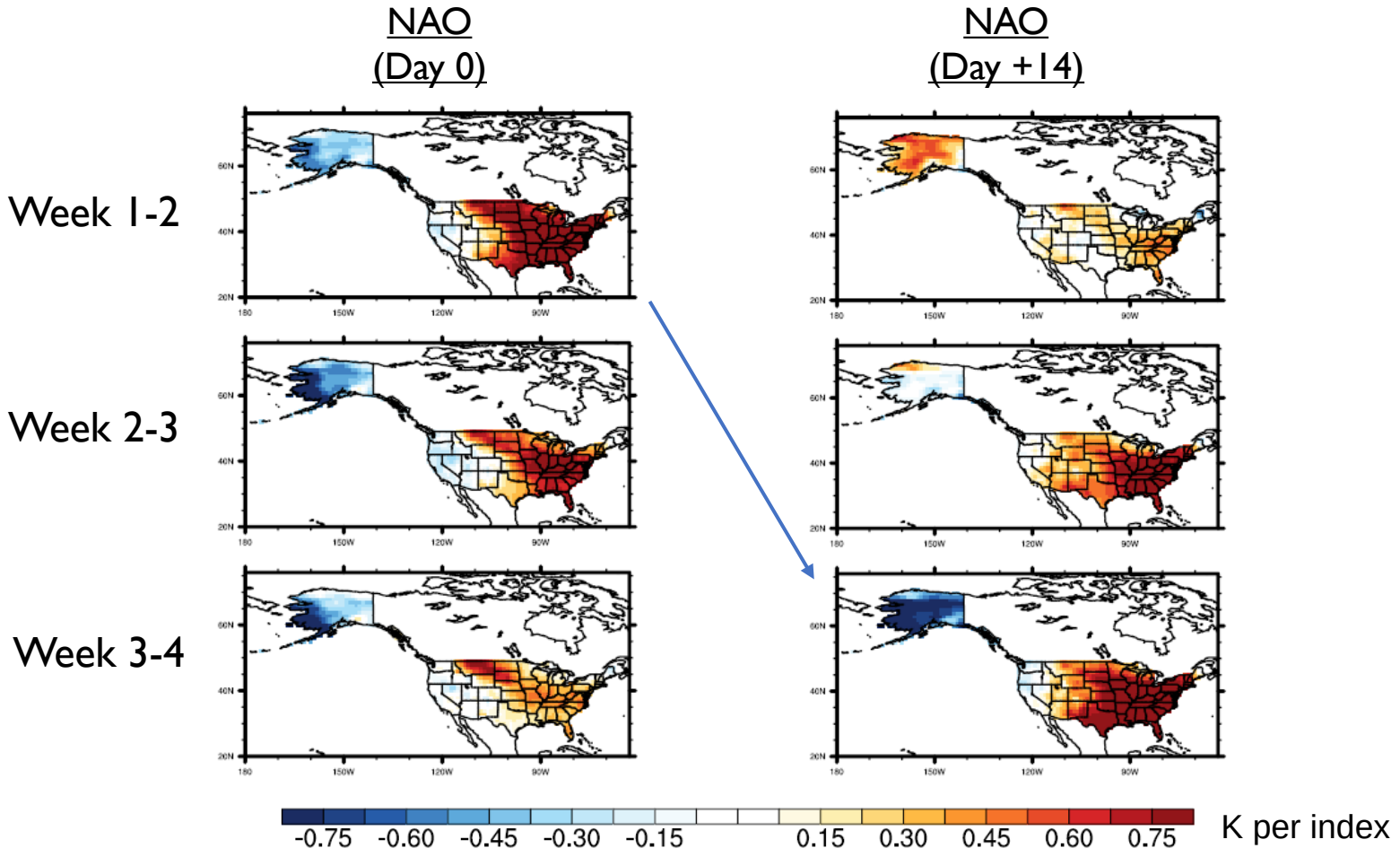
MLR-NAO Schematic (Training)



MLR-NAO Schematic (Verification)



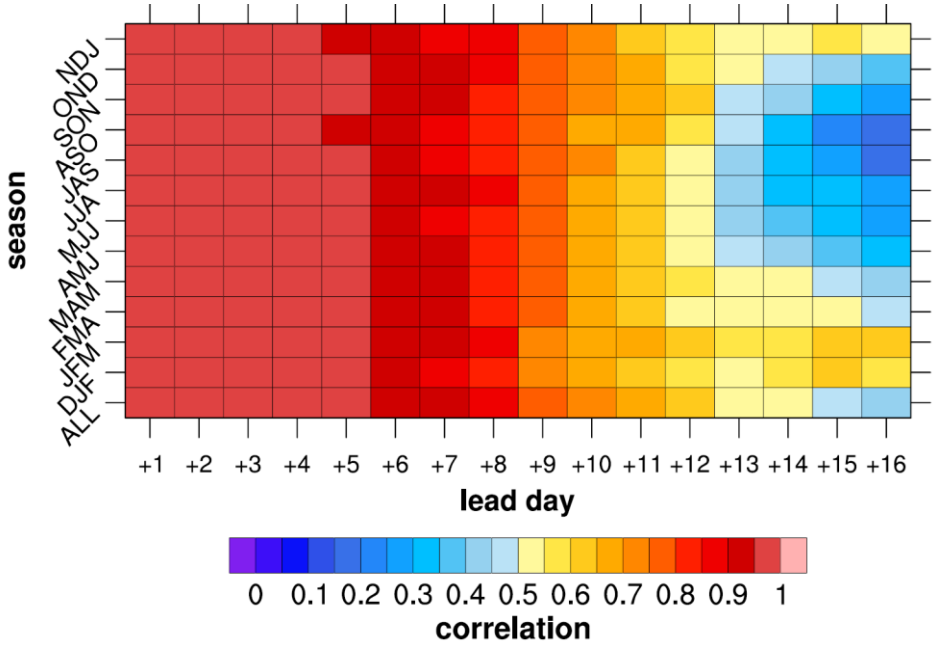
MLR-NAO Regression Coefficients



- Training the MLR-NAO on the observed Day +14 NAO provides a much stronger Week 3-4 signal, so hybridization/bridging the statistical MLR with values of the NAO forecasted by the dynamical models may be ideal.

GEFS NAO Skill Scores

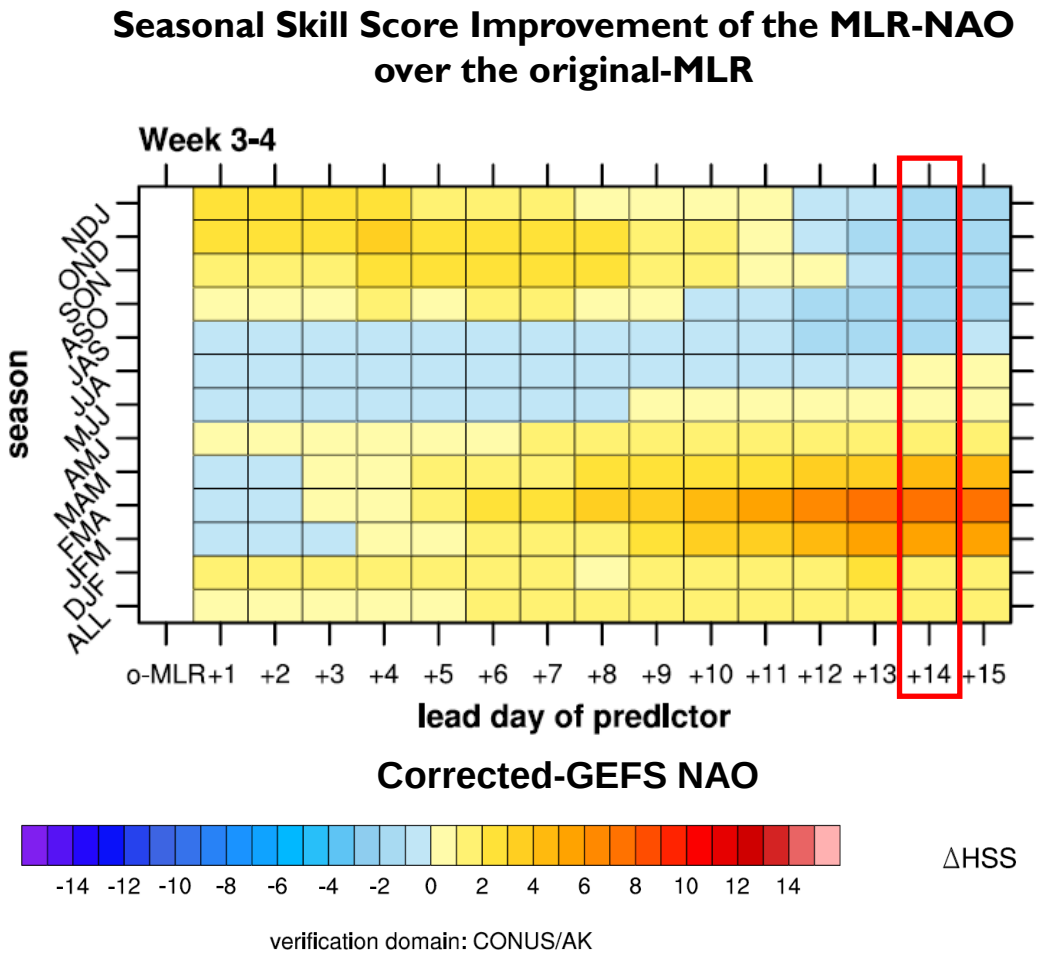
Observed NAO versus GEFS NAO



- GEFS forecast versus observations
- The NAO is based on CPC's methods (RPCA on Z500; Barnston & Livezey 1987)

- NAO skill scores peak in winter, with correlations exceeding 0.5 through Day +14, when averaged across all seasons.

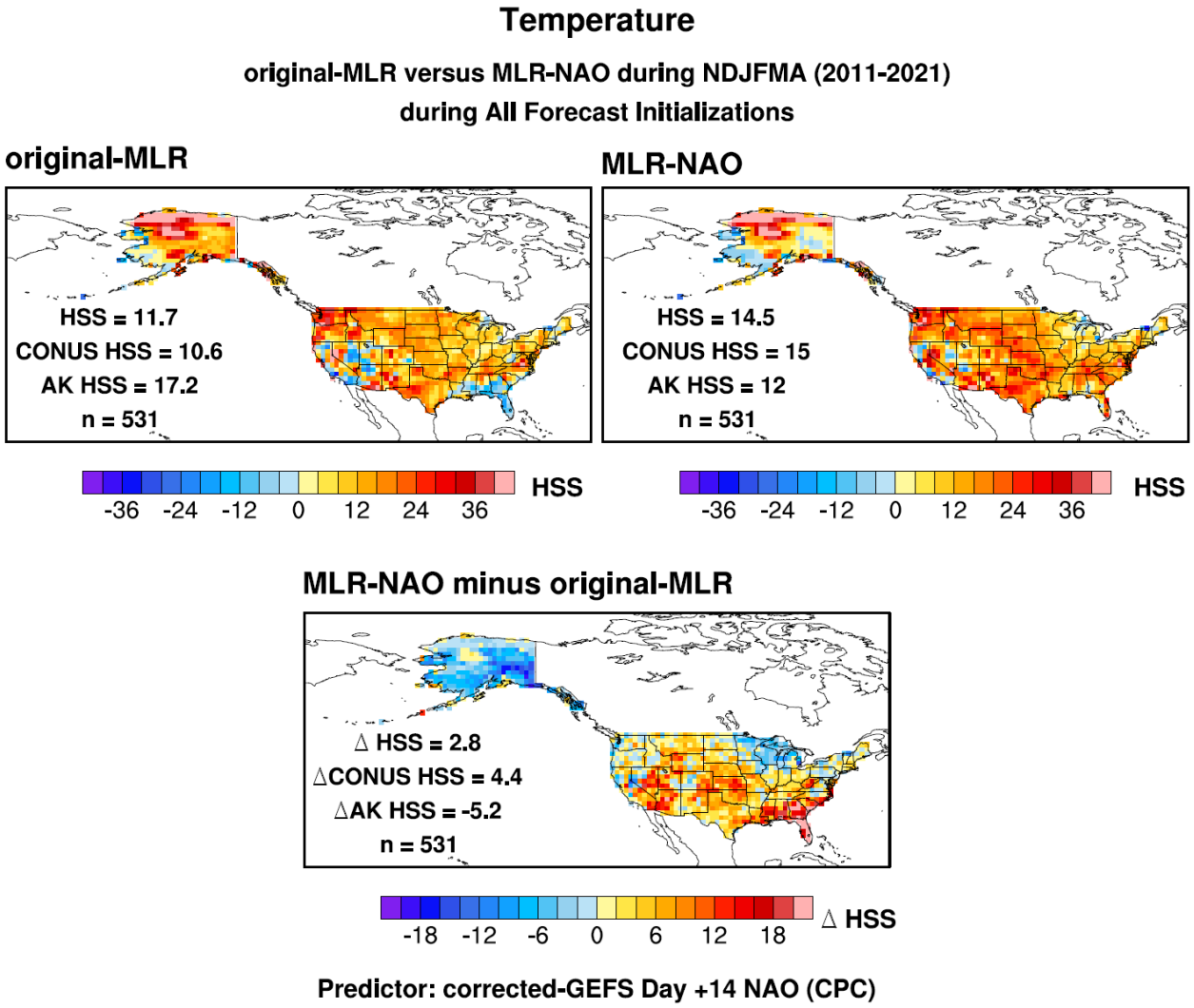
Original-MLR versus MLR-NAO



Difference in Week 3-4 TEMPERATURE skill scores

- **original-MLR versus MLR-NAO**
- **Predictor:** GEFS Days +1 to +15 NAO
- **Verification Period:** 2011-2021, Tuesday and Fridays
- **Key Points:**
  - Generally, the MLR-NAO offers the most improvement during non-summer months.
  - The greatest improvement is provided using the GEFS NAO from Day +14
  - One could make the argument that we should use predictors with smaller leads during fall.

original-MLR versus MLR-NAO

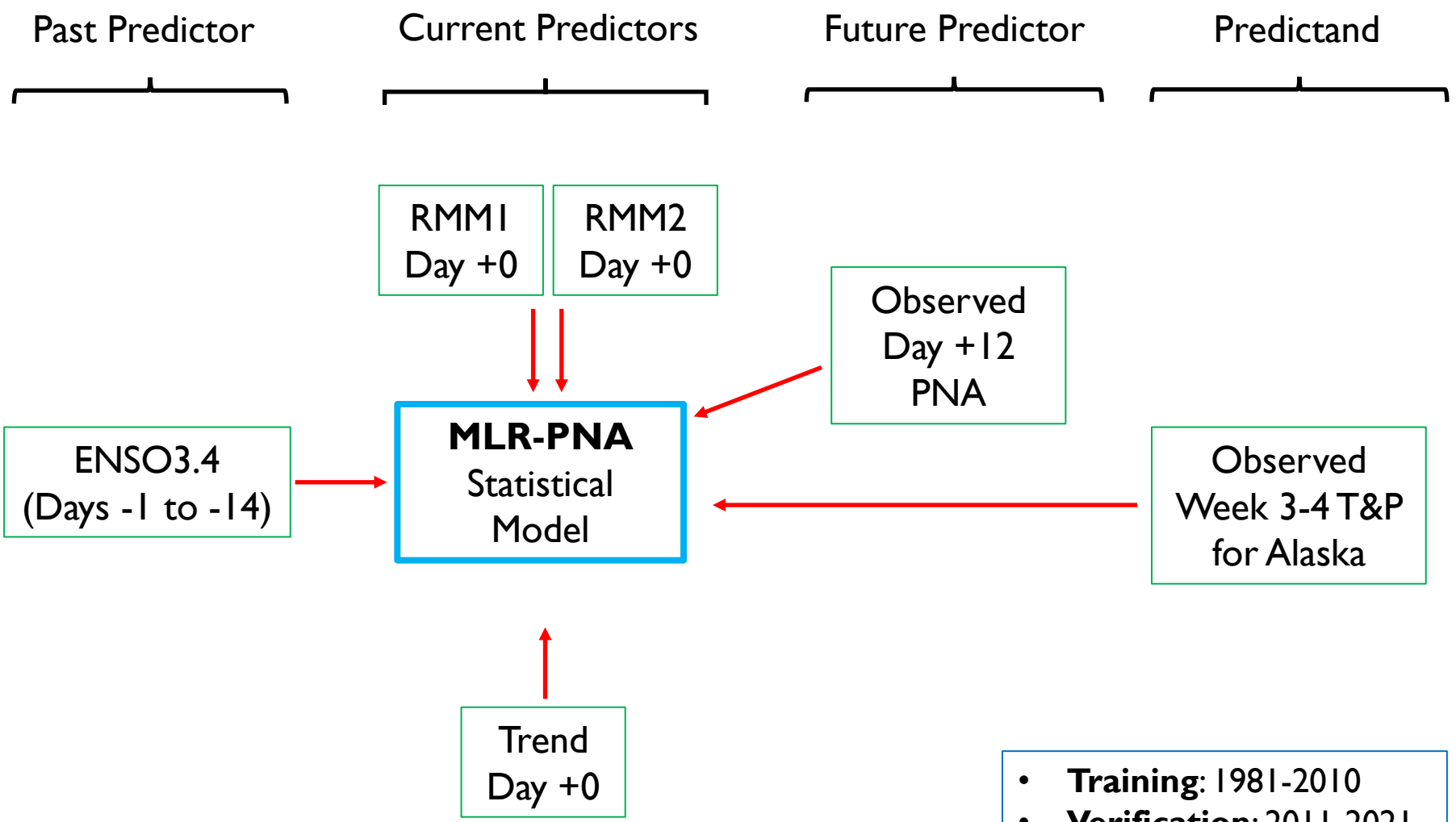


Difference in Week 3-4 TEMPERATURE skill scores

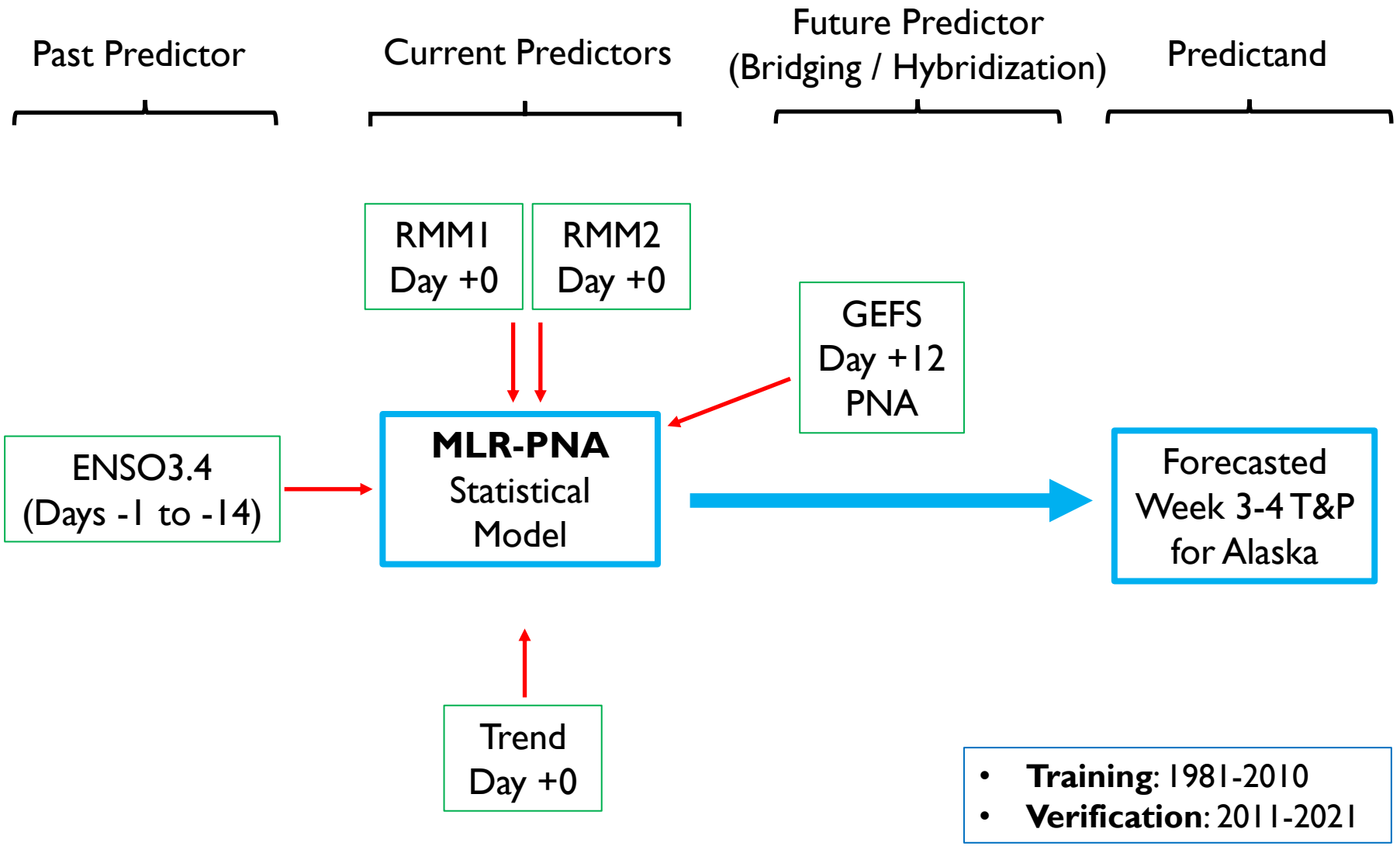
- **original-MLR versus MLR-NAO**
- **Predictor:** GEFS Day +14 NAO
- **Verification Period:** 2011-2021, Tuesday and Fridays
- **Additional Conditions:** during November-April only
- **Key Points:**
  - Overall skill scores improve by ~24%.
  - Generally, the MLR-NAO offers improvements over CONUS and makes things worse over AK.
  - Skill scores over CONUS improve by ~42%.

How does an MLR-PNA perform compared to the original-MLR?

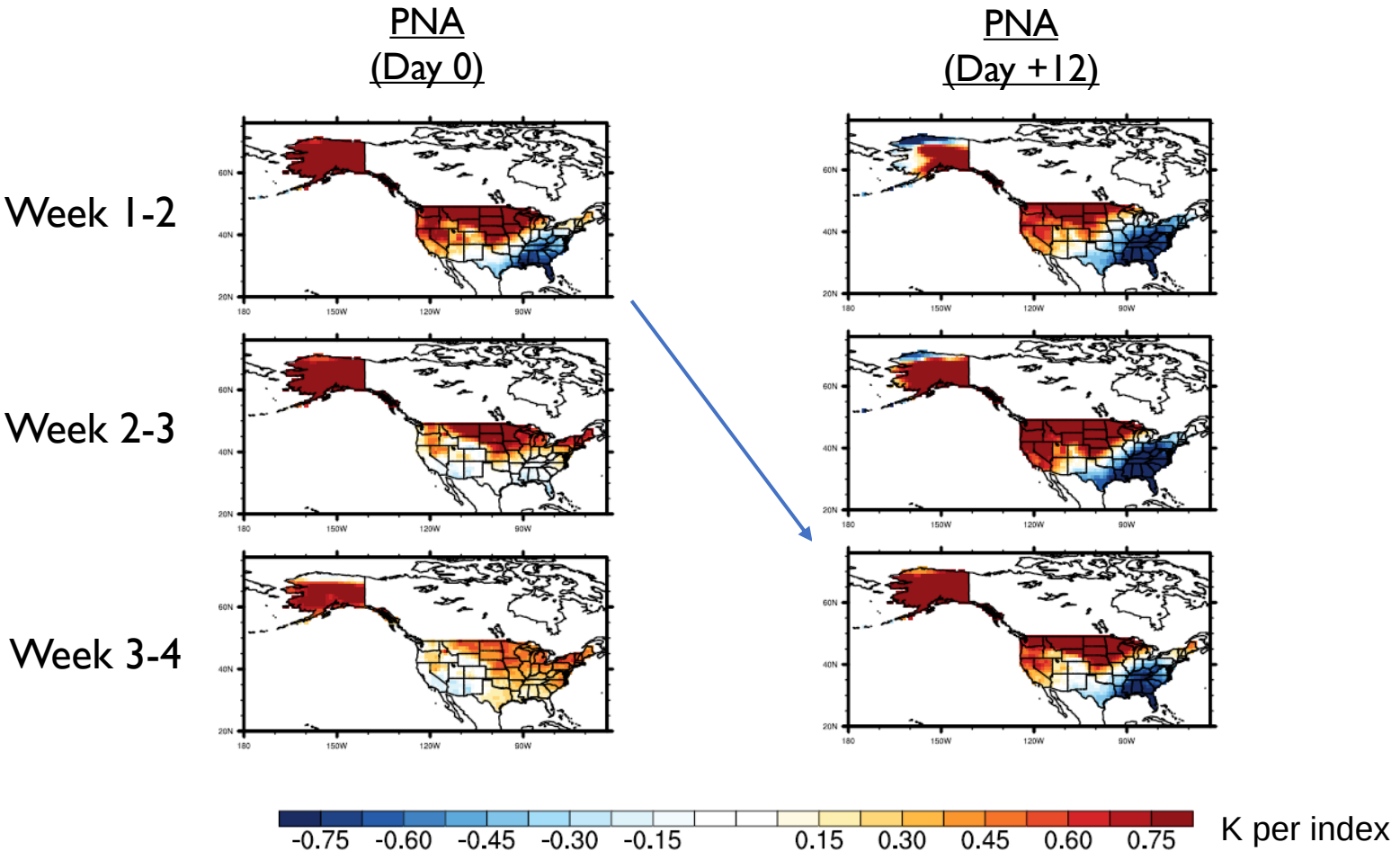
MLR-PNA Schematic (Training)



MLR-PNA Schematic (Verification)



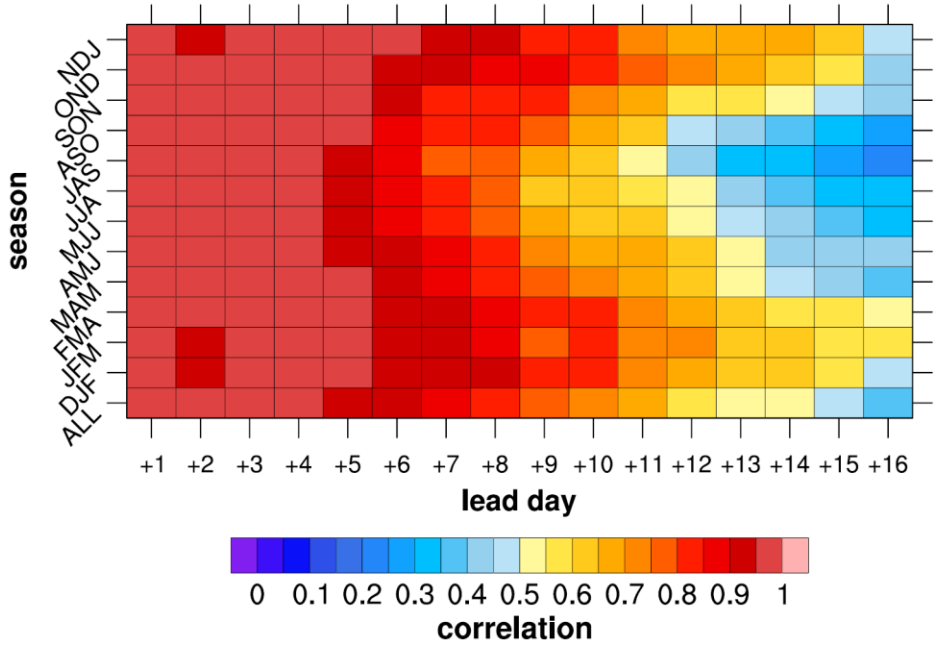
MLR-PNA Regression Coefficients



- Training the MLR-PNA on the observed Day +12 NAO provides a much stronger Week 3-4 signal, so hybridization/bridging the statistical MLR with values of the PNA forecasted by the dynamical models may be ideal.

GEFS PNA Skill Scores

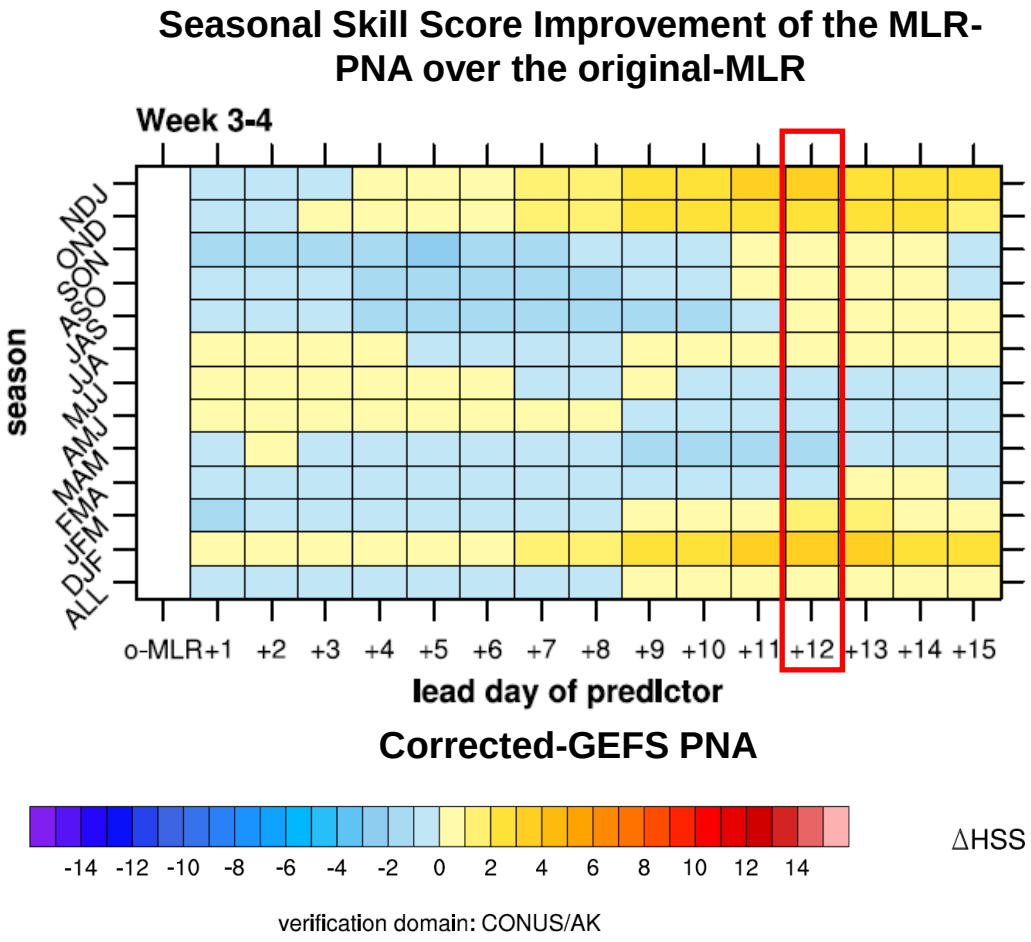
Observed PNA versus GEFS PNA



- GEFS forecast versus observations
- The PNA is based on CPC's methods (RPCA on Z500; Barnston & Livezey 1987)

- PNA skill scores peak in winter, with correlations exceeding 0.5 through Day +14, when averaged across all seasons.

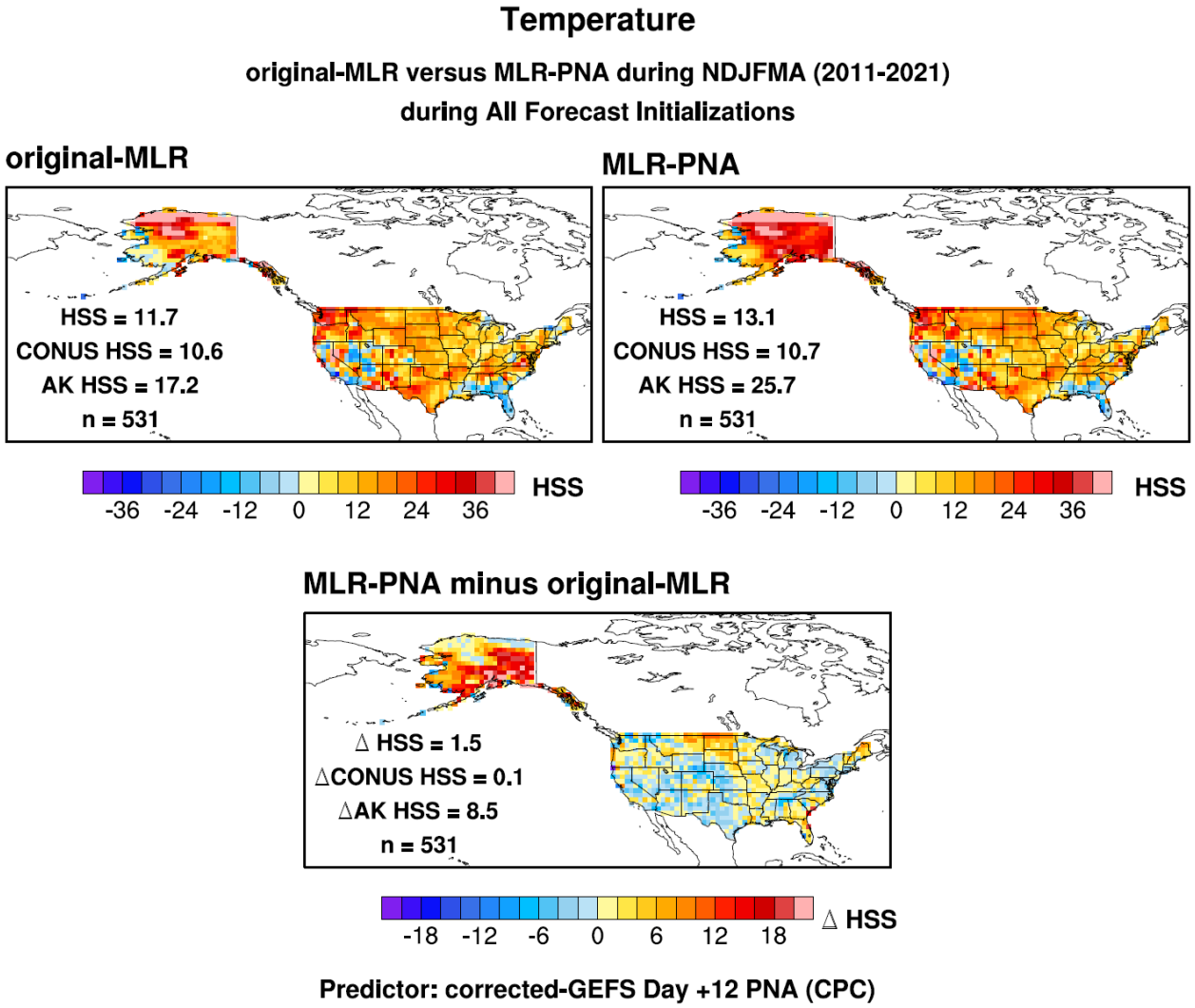
original-MLR versus MLR-PNA



Difference in Week 3-4 TEMPERATURE skill scores

- **original-MLR versus MLR-NAO**
- **Predictor:** GEFS Days +1 to +15 PNA
- **Verification Period:** 2011-2021, Tuesday and Fridays
- **Key Points:**
  - Generally, the MLR-PNA offers the most improvement during non-summer months.
  - The greatest improvement is provided using the GEFS PNA from Day +12

original-MLR versus MLR-PNA



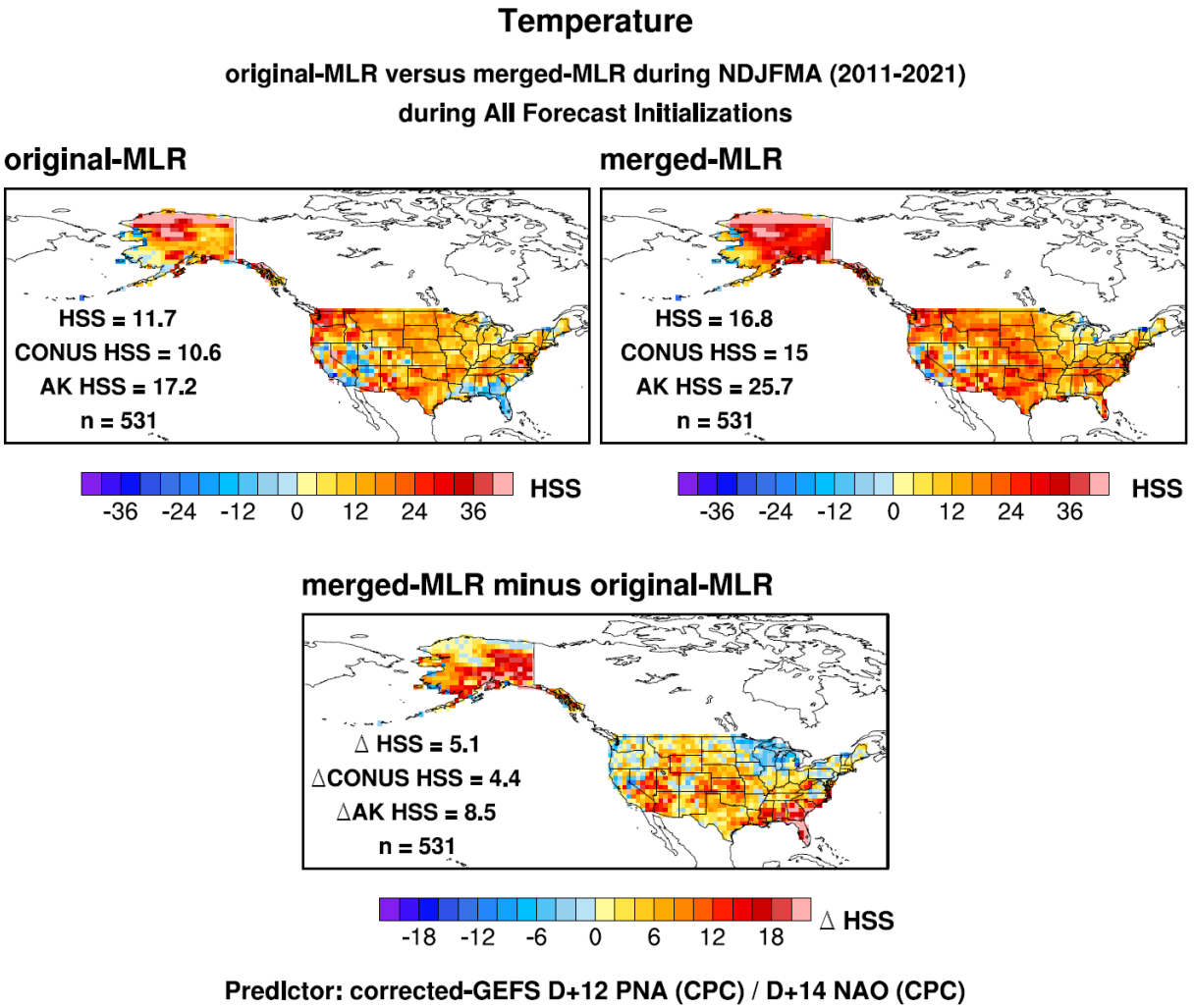
Difference in Week 3-4 TEMPERATURE skill scores

- **original-MLR versus MLR-PNA**
- **Predictor:** GEFS Day +12 PNA
- **Verification Period:** 2011-2021, Tuesday and Fridays
- **Additional Conditions:** during November-April only
- **Key Points:**
  - Overall skill scores improve by ~11%.
  - Generally, the MLR-PNA offers improvements over Alaska and does little for CONUS.
  - Skill scores over Alaska improve by ~49%.

Original-MLR versus Merged-MLR

Should we create a merged-MLR, where we use the MLR-NAO to forecast for CONUS and the MLR-PNA to forecast for Alaska?

Original-MLR versus Merged-MLR



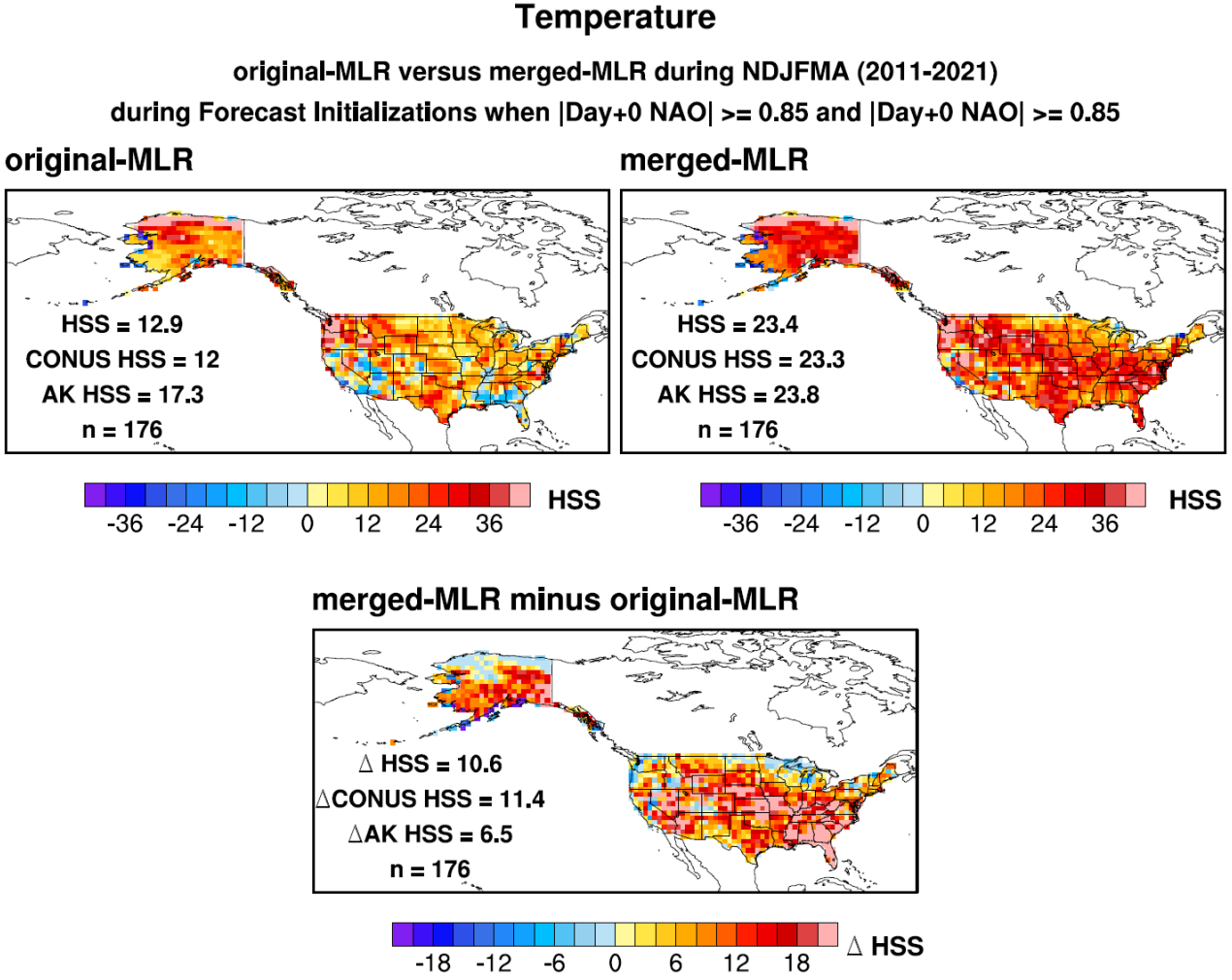
Difference in Week 3-4 TEMPERATURE skill scores

- **original-MLR versus merged-MLR**
- **Predictor:** GEFS Day +14 NAO & GEFS Day +12 PNA
- **Verification Period:** 2011-2021, Tuesday and Fridays
- **Additional Conditions:** during November-April only
- **Key Points:**
  - Overall skill scores improve by ~44%.
  - Skill score improvements exist nearly everywhere except for the Upper Midwest.

Original-MLR versus Merged-MLR

How does the merged-MLR perform during Forecasts of Opportunity?

Original-MLR versus Merged-MLR



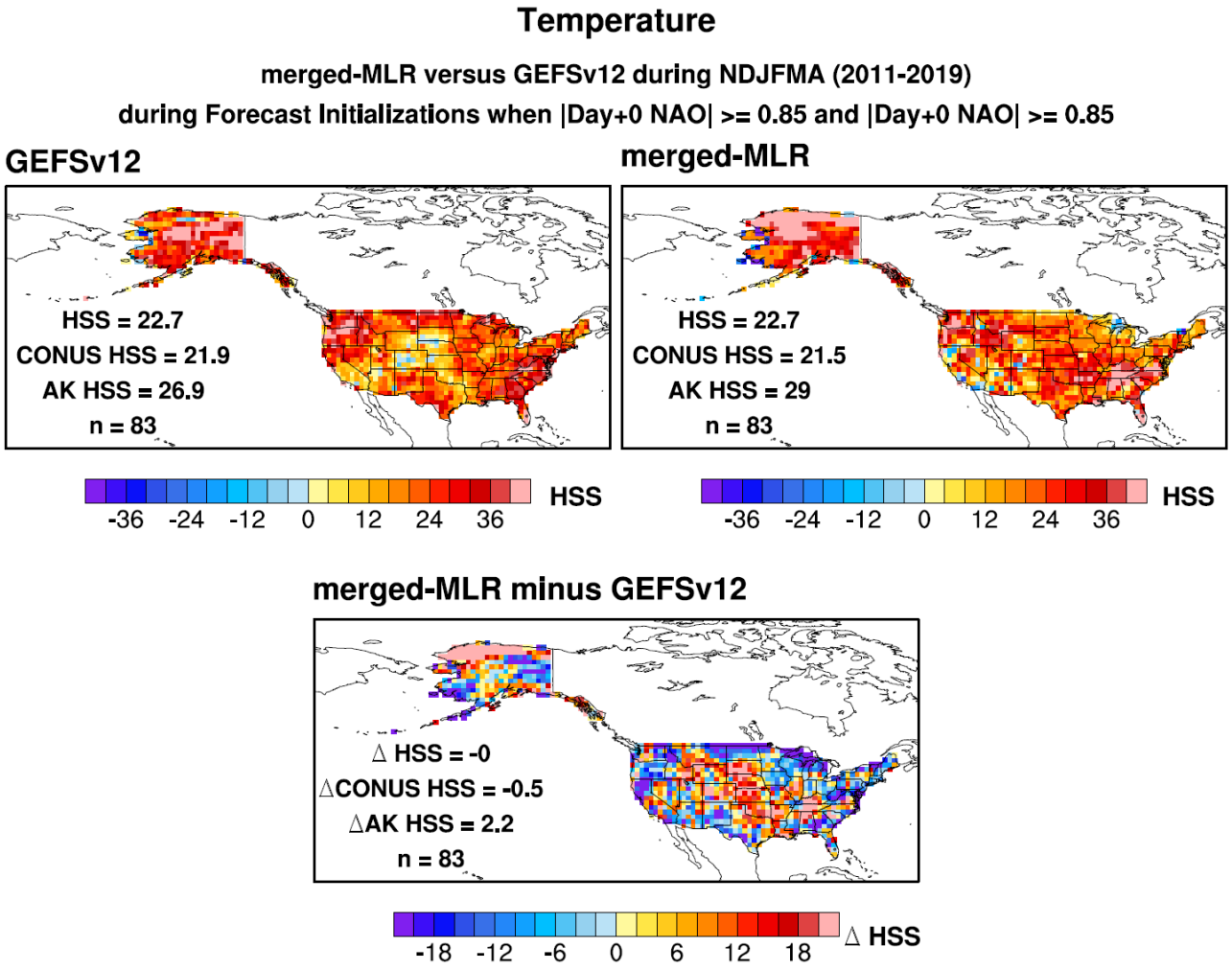
Difference in Week 3-4 TEMPERATURE skill scores

- **original-MLR versus merged-MLR**
- **Predictor:** GEFS Day +14 NAO & GEFS Day +12 PNA
- **Verification Period:** 2011-2021, Tuesday and Fridays
- **Additional Conditions:** during November-April only & when the observed NAO is amplified on Day 0
- **Key Points:**
  - Overall skill scores improve by ~82% over CONUS/AK
  - The greatest improvements are located over the Central Plains and Southeast.
  - Forecasts of Opportunity! (Mariotti et al. 2020)

Merged-MLR versus GEFS

How does the merged-MLR perform compared to the GEFSv12?

Merged-MLR versus GEFS



Difference in Week 3-4 TEMPERATURE skill scores

- **merged-MLR versus GEFS**
- **Predictor:** GEFS Day +14 NAO & GEFS Day +12 PNA
- **Verification Period:** 2011-2019, Thursdays
- **Additional Conditions:** during November-April only & when the observed NAO is amplified on Day 0
- **Key Points:**
  - The GEFS and merged-MLR perform equally well when the NAO is amplified.
  - Skill score improvements are greatest over northern Alaska and central CONUS.
  - Statistical models have a place in forecasting!

Conclusions

- By using blocking-related predictors, such as the NAO and PNA, we can improve our Week 3-4 statistical models.
- Further, by hybridizing the statistical models with indices forecasted by the dynamical models, we gain the most improvement.
- Finally, this improvement largely occurs during so-called "forecasts of opportunity" when the relative indices are amplified. In such instances, the statistical model performs on-par with the GEFSv12.
- Unfortunately, positive results for precipitation have been elusive, but a few more tests are ongoing.
- Moving forward, we will be experimentally monitoring the merged-MLR's performance in real-time, with the particular hope that it can provide insight into upcoming episodes of cold during winter.

References

Baggett, C., S. Lee, and S. Feldstein, 2016: An Investigation of the Presence of Atmospheric Rivers over the North Pacific during Planetary-Scale Wave Life Cycles and Their Role in Arctic Warming. *J. Atmos. Sci.*, **73**, 4329–4347, https://doi.org/10.1175/JAS-D-16-0033.1.

Barnes, E. A., J. Slingo, and T. Woollings, 2012: A methodology for the comparison of blocking climatologies across indices, models and climate scenarios. *Clim Dyn*, **38**, 2467–2481, https://doi.org/10.1007/s00382-011-1243-6.

Barnston, A. G., and R. E. Livezey, 1987: Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. *Monthly Weather Review*, **115**, 1083-1126.

Butler, A. H., J. P. Sjoberg, D. J. Seidel, and K. H. Rosenlof, 2017: A sudden stratospheric warming compendium. *Earth System Science Data*, **9**, 63–76, https://doi.org/10.5194/essd-9-63-2017.

Croci-Maspoli, M., C. Schwierz, H. Davies, 2007: Atmospheric blocking: space-time links to the NAO and PNA. *Climate Dynamics*, **29**, 703-725.

Domeisen, D. I. V., and Coauthors, 2020: The Role of the Stratosphere in Subseasonal to Seasonal Prediction: 1. Predictability of the Stratosphere. *Journal of Geophysical Research: Atmospheres*, **125**, e2019JD030920, https://doi.org/10.1029/2019JD030920.

Domeisen, D. I. V., and Coauthors, 2020: The Role of the Stratosphere in Subseasonal to Seasonal Prediction: 2. Predictability Arising From Stratosphere-Troposphere Coupling. *Journal of Geophysical Research: Atmospheres*, **125**, e2019JD030923, https://doi.org/10.1029/2019JD030923.

Harnos, D. and Coauthors, 2021: Differences in the application of large-scale modes of tropical variability for subseasonal prediction of North American temperature and precipitation. *Weather & Forecasting*, in prep.

Kim, M., C. Yoo, and J. Choi, 2021: Enhancing Subseasonal Temperature Prediction by Bridging a Statistical Model with Dynamical Arctic Oscillation Forecasting. *Geophysical Research Letters*, **48**, https://doi.org/10.1029/2021GL093447.

Marinaro, A., S. Hilberg, D. Changnon, and J. Angel, 2015: The North Pacific-driven Severe Midwest Winter of 2013/14. *Journal of Applied Meteorology and Climatology*, **54**, 2141-2151.

Mariotti, A., and Coauthors, 2020: Windows of Opportunity for Skillful Forecasts Subseasonal to Seasonal and Beyond. *Bull. Amer. Meteor. Soc.*, **101**, E608–E625, https://doi.org/10.1175/BAMS-D-18-0326.1.

Martius, O., L. M. Polvani, and H. C. Davies, 2009: Blocking precursors to stratospheric sudden warming events. *Geophysical Research Letters*, **36**, https://doi.org/10.1029/2009GL038776.

Quinting, J. F., and F. Vitart, 2019: Representation of Synoptic-Scale Rossby Wave Packets and Blocking in the S2S Prediction Project Database. *Geophysical Research Letters*, **46**, 1070–1078, https://doi.org/10.1029/2018GL081381.

Tibaldi, S., F. Molteni, 1990: On the operational predictability of blocking. *Tellus*, **42A**, 343-365.

Wang, C., H. Liu, and S.-K. Lee, 2010: The record-breaking cold temperatures during the winter of 2009/2010 in the Northern Hemisphere. *Atmospheric Science Letters*, **11**, 161–168, https://doi.org/10.1002/asl.278.

Wise, E. K., 2016: Five centuries of U.S. West Coast drought: Occurrence, spatial distribution, and associated atmospheric circulation patterns. *Geophysical Research Letters*, **43**, 4539–4546, https://doi.org/10.1002/2016GL068487.

Extra Slides

Outline

Introduction

- Why do we care about blocking?
- A brief overview of CPC's forecasting process
- What is CPC's Multiple Linear Regression Model (original-MLR)?

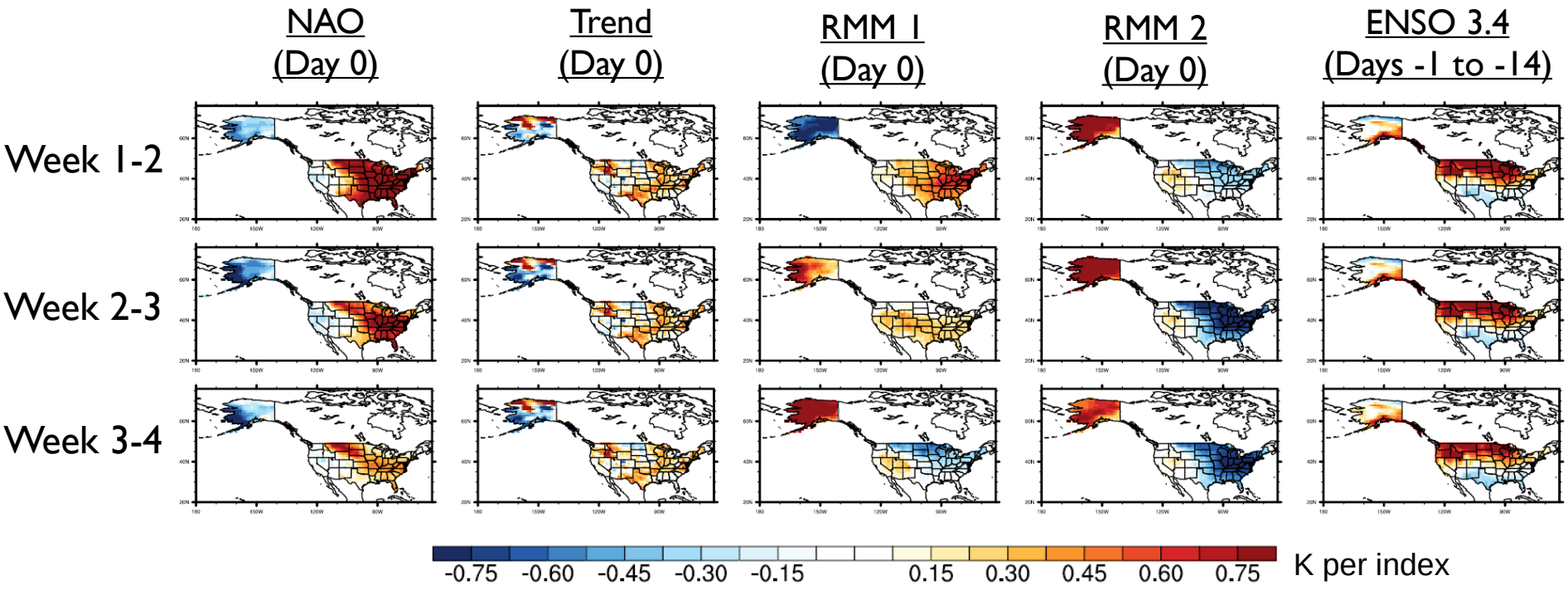
Results

- How does an MLR-NAO perform compared to the original-MLR?
- How does an MLR-PNA perform compared to the original-MLR?
- Should we create a merged-MLR, where we use the MLR-NAO to forecast for CONUS and the MLR-PNA to forecast for Alaska?
- How does the merged-MLR perform during Forecasts of Opportunity?
- How does the merged-MLR perform compared to the GEFSv12?

Conclusions

MLR-NAO Regression Coefficients

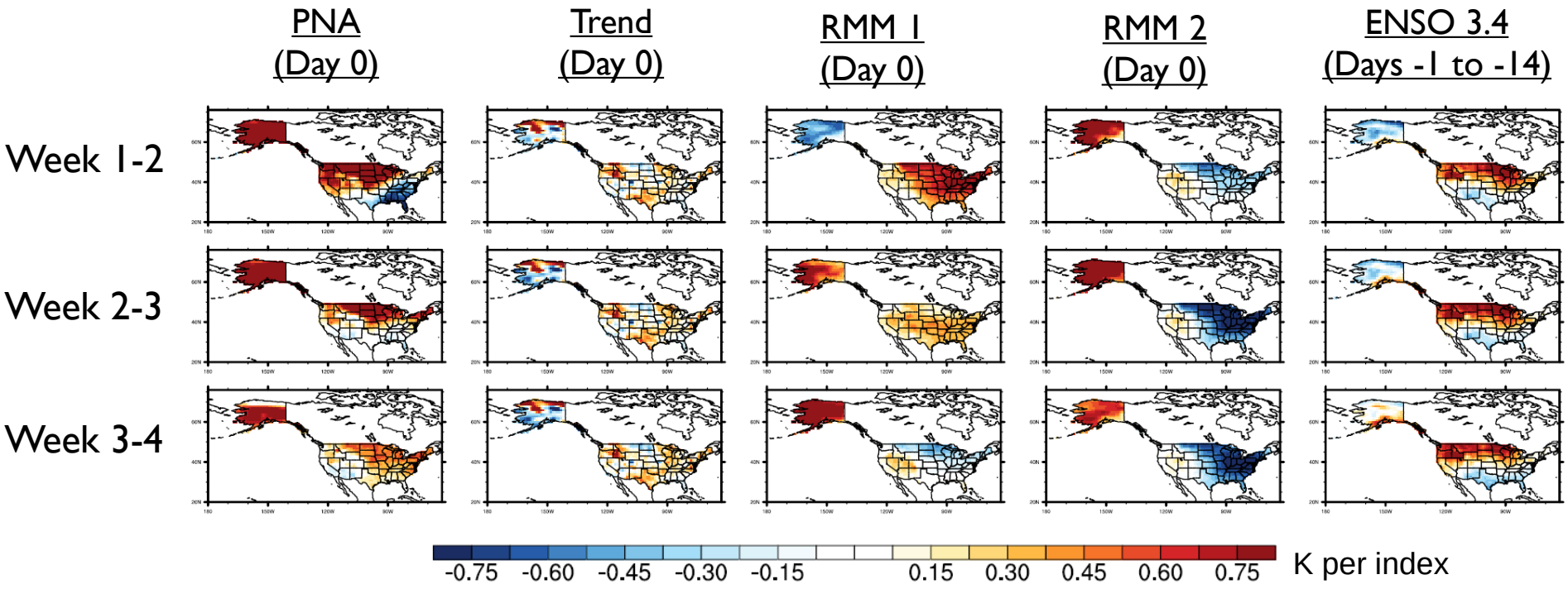
Temperature



- Trend remains constant with lead-time.
- MJO and ENSO signals are large across all leads ands persist out to Week 3-4.
- The large NAO signal over CONUS fades significantly by Week 3-4.

MLR-PNA Regression Coefficients

Temperature



- Trend remains constant with lead-time
- MJO and ENSO signals are large across all leads ands persist out to Week 3-4
- The PNA signal tends to fade toward Week 3-4